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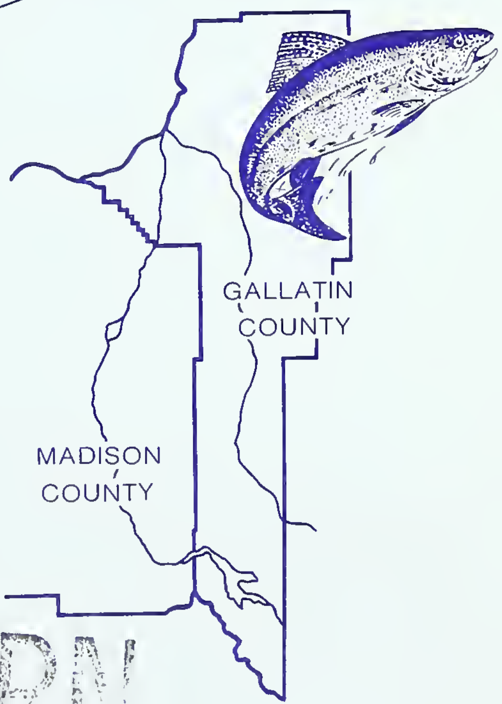
MADISON RIVER THERMAL STUDY
FINAL REPORT
DECEMBER 1983

Blue Ribbons of the Big Sky Country

Areawide Planning Organization



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ON THE

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Blue Ribbons of the Big Sky Country

Areawide Planning Organization

Bozeman, Montana

December 1983

Work Performed Under This Study Was Financed In Part by A Grant From The State of Montana Under the Renewable Resources Development Program

ACKNOWLEDGEMENTS

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The members of the Blue Ribbons Administrative Board who served as the Executive Committee and administered this grant study were Walter Sales, Chairman, Chuck Aaberg, and Bob Storey.

The assistance of the members of the Madison River Advisory Committee throughout the initial phases of the thermal investigations and during the studies conducted under this grant is greatly appreciated.

Various individuals, organizations and agencies made significant contributions of time, manpower, and money to the thermal studies and are called out for special recognition:

- Department of Fish, Wildlife & Parks
  - Ron Marcoux, Regional Fisheries Manager (until July 1981)
  - Jerry Wells, Regional Fisheries Manager (after July 1981)
  - Dick Vincent, Madison River Fisheries Biologist
- Madison Gallatin Chapter of Trout Unlimited
- Montana State University
- U. S. Bureau of Land Management
- U. S. Bureau of Reclamation
- U. S. Geological Survey

This final report was authored by Joel A. Shouse P. E., Executive Director of Blue Ribbons.

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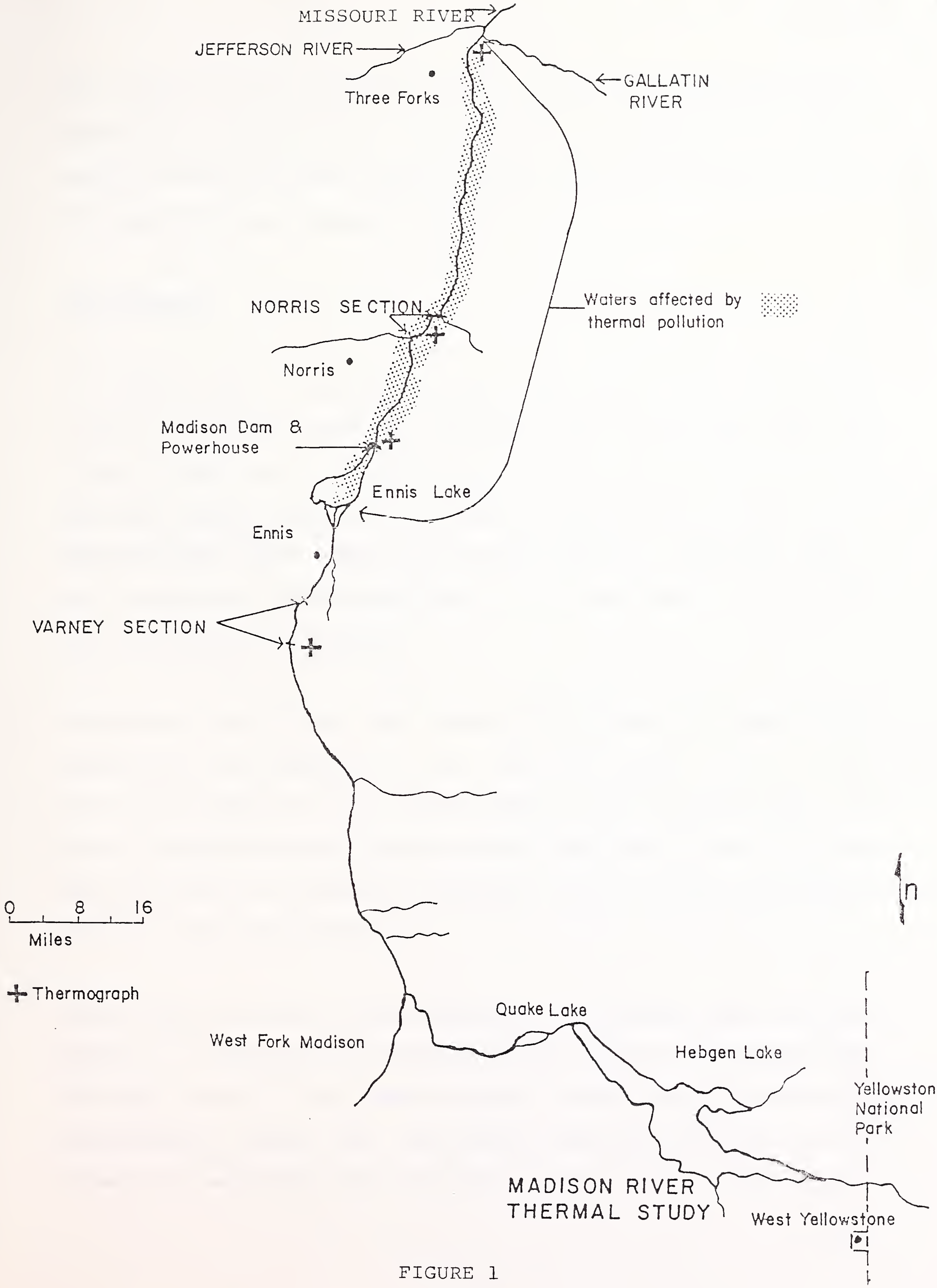
INTRODUCTION

Blue Ribbons of the Big Sky Country Areawide Planning Organization (Blue Ribbons) was organized in June 1975 as the water quality planning agency for the Madison and Gallatin River drainages in southwestern Montana. It was sponsored by thirteen local government entities and was funded under an EPA water quality planning grant (Section 208 of the 1972 amendments to P.L. 92-500; later the 1977 Clean Water Act) and through funds from the local sponsors. Blue Ribbons was charged with the development of a Water Quality Management Plan for its planning area. Such a plan was completed and published in August 1979.

One of the water quality problems addressed by Blue Ribbons was thermal pollution of the lower 35 miles of the Madison River (See Figure 1). This problem was identified during the formative stages of Blue Ribbons by the Montana Department of Fish, Wildlife and Parks (FW&P) and by the Montana Department of Health and Environmental Sciences. Although funding limited Blue Ribbons from conducting any major new studies, an investigation of the thermal pollution problem was made through the auspices of a Madison River Thermal Advisory Committee. One of the results of this investigation was the creation of a computerized thermal model of the river by FW&P and the Billings Regional Office of the U. S. Bureau of Reclamation (BuRec). Operation of this model established that certain alterations of the river system could improve the temperatures in the lower Madison River.

In 1980 Blue Ribbons applied to the Montana Department of Natural Resources under the Renewable Resources Development Program for a grant to evaluate more fully the alternatives identified in the earlier work. The 1981 session of the Montana Legislature approved a grant of $125,000 for this work.



MISSOURI RIVER
JEFFERSON RIVER
Three Forks
GALLATIN
RIVER
NORRIS SECTION
Waters affected by
thermal pollution
Norris
Madison Dam &
Powerhouse
Ennis Lake
Ennis
VARNEY SECTION
0
8
16
Miles
Thermograph
n
Quake Lake
West Fork Madison
Hebgen Lake
Yellowstone
National
Park
MADISON RIVER
THERMAL STUDY
West Yellowstone

FIGURE 1

This report presents the findings of the studies and investigations of the Madison River Thermal Study. Part I is a narrative summary and Part II contains copies of pertinent previous reports and reports prepared under the Renewable Resources Development Program Grant.

BACKGROUND

The Madison River is perhaps Montana's most famous "Blue Ribbon" trout stream and has been nationally acclaimed as one of the finest wild trout streams in the country. Fisherman from every state and some from other countries annually throng to the Madison to experience its fabled fishing. Needless to say, sport fishing on the Madison River is a significant factor in the local economy. Not to be overlooked are the recreational values which the river has to local area residents.

Temperature levels in the lower Madison River during the summer months severely limit the catchability of trout. This is, of course, the time at which most of the resident and non-resident fishermen wish to fish the river. The area of temperature concern begins at Ennis Lake and continues downstream some 35 miles to the Madison's confluence with the Gallatin and Jefferson Rivers at Three Forks (Figure 1).

Ennis Lake was created by the construction of the Madison Dam and Power-house by a predecessor of the Montana Power Company in the early 1900's. The lake is part of a two reservoir system whereby actual water storage is accomplished at Hebgen Lake, some 50 miles upstream from Ennis Lake, and releases are made from Hebgen to Ennis according to need. The operational

management is such that Ennis Lake remains at a fairly constant level throughout most of the year. The lake has a surface area of approximately six square miles. A study conducted by FW&P in 1976 determined that the lake had a volume of 34,675 acre-feet, an average depth of 9.17 feet, and average flow-through time of 11.7 days.

As long ago as 1961, FW&P conducted a temperature study on the Madison which indicated a considerable warming of the river below Ennis Lake. In 1972, four continuous recording thermographs were placed in the stream, one above Ennis Lake and three below (Figure 1). Temperature data have been gathered for the period March 1 to October 31 for every year since 1972. This data shows mean water temperatures in the lower river to be up to 10-12°F higher than mean water temperatures in the upper river during the summer months. General warming of the lower river begins in mid-March, peaks in late July or early August, and ceases by mid-October. The maximum temperature observed in the lower river has been 82°F which is within a few degrees of what is considered to be lethal for trout.

In 1976, FW&P initiated a fishery study to annually obtain fish population estimates and monthly trout growth rates for the May to September period for a section of river above Ennis Lake (Varney) and a section below (Norris).

Initial results suggested that trout above Ennis Lake grew faster and were in better condition than those below. FW&P also suggested that a trend toward increasing numbers of large trout above the lake versus lower numbers below the lake might be occurring. The slower growth rates below the lake were felt to possibly be due to the higher water temperatures in the prime growth

period (June-September), or to changes in the food chain due to the higher temperatures, or a combination of both. These observations were reported by FW&P in a Job Progress Report entitled Madison River Temperature Study by Richard Vincent, dated March 28, 1977.

FW&P brought their concerns over the high water temperatures in the lower Madison River to Blue Ribbons at the time of the formulation of the Blue Ribbons work program. They expressed their feelings that perhaps Ennis Lake was acting as a solar heat collector due to its shallow depth and lengthy flow-through time. Maximum temperatures in the lower river were dangerously close to lethal levels for trout and catchability during summer months was severely curtailed.

The temperature problem of the lower Madison River was also identified by the Montana Department of Health and Environmental Sciences in the 303(e) Basin Plan which they had prepared for the Upper Missouri Headwaters Basin in 1975.

EARLY BLUE RIBBONS STUDIES AND INVESTIGATIONS

As has been previously stated, at the time of creation of the Blue Ribbons program in 1975 it was recognized that the thermal problem of the lower Madison River was a water quality problem and that it should be addressed by Blue Ribbons. A Madison River Thermal Advisory Committee was created to direct Blue Ribbons activities and studies in regard to the matter. Membership on the committee consisted of representatives from:

Montana Department of Fish, Wildlife and Parks (FW&P)

Montana Power Company (MPC)

U. S. Fish and Wildlife Service

Bureau of Land Management (BLM)

Madison-Gallatin Chapter of Trout Unlimited (TU)

Madison County Commission

Madison Conservation District

Madison County Planning Board

Soil Conservation Service (SCS)

Montana Department of Health and Environmental Sciences,
Water Quality Bureau (WQB)

Montana State University (MSU)

U. S. Geological Survey (USGS)

Blue Ribbons Staff and Technical Advisory Council

The committee gathered input from FW&P, MPC, Sportsman groups and local citizens. It also met with representatives of the Federal Power Commission, now the Federal Energy Regulatory Commission, under whose permit MPC operates the electrical generation facilities. Members of the committee assisted FW&P in the field work associated with the preparation of a bottom contour map of Ennis Lake. Several significant studies were also undertaken under the auspices of the committee and by others which are described in the following.

During August of 1977 a thermal infrared photo flight of the river from Three Forks to Quake Lake was made to locate possible heat sources. This work was done by the USGS with financial assistance provided by Blue Ribbons

($5,000), FW&P ($4,500), and TU ($500). The result of this work identified Ennis Lake as the only significant heat source to the lower Madison River. The temperature profiles obtained were also eventually used in the calibration of computer thermal models.

From 1976 to 1978 a study of the aquatic insect life in both the upper and lower Madison River was conducted by John Fraley, a graduate research assistant at Montana State University and an employee for the Montana Cooperative Fisheries Research Unit. The purpose of the study was to determine the effect the warmer water in the lower river had on aquatic insects. The results showed substantial differences in the aquatic life and a tendency toward warmer water organisms in the lower river.

As a result of the various investigations of the committee a series of possible alternative actions were developed which it was thought would alleviate the thermal problem. These alternatives were as follows:

1) Lower the level of Ennis Lake, thereby reducing the flow-through time and the period of warming.
2) Increase the depth of Ennis Lake to where stratification would occur and cooler water could be discharged.
3) Channel the river through the lake in a dike system to prohibit its warming.
4) Pipe the river through the lake to prohibit its warming.
5) Dredge Ennis Lake to a depth where stratification would occur and cooler water could be discharged.

During 1977 discussions took place between the committee and the Billings Regional Office of the BuRec as regards temperature modeling of the river. BuRec had a great deal of experience in both reservoir and river modeling and the necessary data appeared to be available. Their computer modeling programs and temperature modeling expertise were made available to the committee with certain limitations on their level of involvement.

Mr. Richard Vincent, fisheries biologist for the Madison River for FW&P who had conducted most of the FW&P studies previously discussed, was assigned the responsibility to work with the BuRec as local coordinator. The specific objectives of the work were to develop a working computer thermal model and to test the model with the various alternatives outlined above to determine what temperatures would result in the lower river. This work took place during 1978 and early 1979. In addition to the principal contributions of effort from FW&P and BuRec, minor manpower assistance was provided by Blue Ribbons and some funding made available by TU and BLM for analysis of the computer printouts.

The computer model work was accomplished for the years 1973 and 1977. The results showed that the alternatives of a) raising the reservoir level, b) reducing the reservoir's surface area through diking, and c) complete channeling or dam removal, offered the greatest reductions in temperatures in the lower river with the latter two being the most promising. The results were significant as they showed that mean temperatures could be reduced 5-7° during the warmest months and that maximum temperatures could be reduced to 75°F or less. It was recommended that these alternatives be further studied to define the most feasible solution. Studies needed included engineering, economic and environmental analysis.

The computer model work is summarized in a report entitled Madison River Thermal Simulation Study which is dated February 11, 1981. This report is contained in Part II.

GRANT APPLICATION

Due to the very encouraging results of the computer model work, the Thermal Advisory Committee concluded that there were options available to improve the temperature conditions in the lower Madison River. The next step in the investigation would be to perform engineering studies of the various alternatives to determine just how they would be accomplished, what they would cost, what would be the environmental impacts, and what would be the overall economic impacts. This would allow the identification of the most feasible alternative and enable an analysis of possible sources of funding for implementation of the solution.

The committee analyzed the various agencies and programs which might fund the next round of studies. The Renewable Resource Development Fund administered by the Montana Department of Natural Resources and Conservation (DNRC) appeared to be the most applicable. Discussions were held with the DNRC staff and on October 15, 1980, an application for funding which included a proposed work program and budget of $125,000 was submitted.

DNRC included the Lower Madison Thermal Study Program in their recommended list of projects to be funded by the Renewable Resource Development Fund which was submitted to the 1981 Montana State Legislature. Support for the project came from sportsman's groups who were concerned for the lower

Madison fishery and from local communities, chambers of commerce, and other interests who were concerned about the economic aspects of the thermal problem on local businesses who serve the out-of-area sport fisherman. After a lengthy hearing process the Legislature finally approved a grant to Blue Ribbons of $125,000 with funds to become available on July 1, 1981.

GRANT STUDIES

Work Program

Upon receipt of the grant, the Madison River Thermal Advisory Committee immediately began work on a detailed work program. The stated objectives of the program were "To evaluate the feasibility, cost and environmental impacts of implementation of the alternative solutions to the thermal pollution problems of the lower Madison River."

The alternatives to be studied included the four which offered the greatest temperature reductions in the previous computer modeling work. They were the following: Alternative A - Raise the level of the reservoir 40 feet; Alternative B - Reduce the active reservoir surface area by 80% by diking; Alternative C - Channel the river around the reservoir; and Alternative E - - Remove the dam. In addition, during the legislative hearings several legislators requested that the alternative of deepening the reservoir by dredging or excavation be explored further due to their personal experience with other reservoirs where precious metals had made this type of methodology cost effective. The committee included this alternative as Alternative D. The committee also discussed the fact that during the computer modeling work the

alternative of lowering the reservoir level gave incomplete results. As there were strong feelings that this alternative should be more thoroughly analyzed due to its ease and low cost of implementation, it was included as Alternative F.

The committee discussed the various options for performing the work. It was their concensus that consultants should be retained for the engineering, economic and environmental work and that the Executive Director of the Blue Ribbons program should handle the administration of the grant program. In addition, legal counsel should be retained and some funds should be budgeted for a finance element to seek funds for implementation of the preferred alternative. The committee would serve as advisor to the study but the final authority would be a three member executive committee made up of members of the Blue Ribbons Administrative Board.

It was decided to divide the work into five phases. From the previous work some very rough estimates had been made of the construction cost associated with the alternatives. Based on these estimates, serious questions had been raised in regards to the feasibility of several of the alternatives. Therefore, the first phase of the work program would refine the rough construction cost estimates and preliminarily estimate the benefits of each alternative. The second phase would review this preliminary information and perhaps delete specific alternatives from further consideration. The third phase would be detailed studies of the remaining alternatives. The fourth phase would review the detailed information and the fifth phase would be a finalization of the studies and preparation of associated reports.

The initial program budget would be as follows:

Engineering	$ 35,000
Economic	30,000
Environmental	20,000
Legal	5,000
Finance	5,000
Administration	30,000
	$125,000

The time frame for the grant was from July 1, 1981, to June 30, 1983. The flow chart for the performance of the various elements of the work is shown as Figure 2.

Consultants

A Request for Proposals was developed by the committee and mailed to some 27 consultants and agencies in November 1981. The listing of consultants and agencies was developed from the "Yellow Pages" in Bozeman and Helena and through personal knowledge of members of the committee. A total of eleven proposals were received to do all or portions of the engineering, economic or environmental work.

FIGURE 2

MADISON RIVER THERMAL PROGRAM

FLOW CHART

WORK ELEMENT	3/81	4/81	1/82	2/82	3/82	4/82	1/83	2/83
Engineering								
1st Phase		--	--					
Review			--					
3rd Phase				----	--			
Review					--			
5th Phase						--		
Economic								
1st Phase		--	--					
Review			--					
3rd Phase				----	--			
Review					--			
5th Phase						--		
Environmental								
1st Phase		--	--					
Review			--					
3rd Phase				----	--			
Review					--			
5th Phase						--		
Legal		----	----	----	----	----	--	
Finance					---	----	--	
Administration								
Liason	----	----	----	----	----	----	----	
$ Management	---X	----X	----X	----X	----X	----X	----X	
Work Programs	----	--						
Contracting		---	----	----	----	---		
Coordination	----	----	----	----	----	----	----	
Reporting	X	X	X	X	X	X	X	
Public Information		---	----	----	----	----	----	

After a thorough review of the proposals, the committee voted unanimously to recommend to the executive committee that the firm of Morrison-Maierle, Inc., of Bozeman and Helena, be retained to do the engineering work. The committee decided to interview two firms for the economic work after which T.A.P., Inc., of Bozeman was recommended to be retained. A number of meetings were held by the committee to review the proposals for the environmental work and supplemental information was requested on their limnological capabilities. Ultimately, the committee decided to recommend that no environmental contract be awarded under the Request for Proposals. The executive committee considered the recommendations and voted to hire Morrison-Maierle and T.A.P. and to reject all proposals for the environmental work. The executive committee also decided to retain John P. Scully of the firm of Scully and Lilly, Attorneys at Law, of Bozeman, as legal counsel.

The Advisory Committee was subsequently approached by several fish and wildlife faculty members from the Department of Biology at Montana State University (MSU) who had developed a program on behalf of the Biology Department to do the environmental work. They stressed the faculty's commitment to public service in areas of their expertise and their intrigue with the Madison River thermal problem. The committee met with the faculty members several times and finally concluded that the desired expertise existed among the faculty and that a cost effective study was being proposed. The executive committee concurred and MSU was retained to do the environmental work.

All contracts with the consultants were executed by April 30, 1982, and work was initiated on Phase 1 of the work program.

Phase 1 Investigations

The basic purpose of the Phase 1 investigations was to do sufficient preliminary work to enable a determination of the basic feasibility of the alternatives and perhaps eliminate some from the further detailed studies to be accomplished under Phase 3. The principal work done under Phase 1 consisted of the following:

1. Collection of bottom samples from Ennis Lake to determine the amount of sediment, the engineering properties of the bottom materials, the suitability of the bottom materials for use as agricultural lands, and the amount of economic minerals contained in the sediments. This work was to be done by Morrison-Maierle.
2. Collection and analysis of independent samples by the Earth Sciences Department of MSU for economic mineral content.
3. Development of preliminary construction costs for each alternative by Morrison-Maierle.
4. Development of preliminary economic impacts for each alternative by T.A.P.

Sixteen bottom samples were taken from Ennis Lake by Morrison-Maierle. The amount of sediment deposition was considerably less than had been anticipated by the Advisory Committee. Delta-type deposits occupy the upper twenty-five percent of the lake and vary in thickness from ten to fifteen feet. The downstream toe is generally from one to six feet in thickness. The total depth of sediments was not penetrated in most of these locations and had to be estimated. Sediment depth in the center of the lake was found to be less

than one foot and consisted of a fine-grained silt. Other than the coarser materials found at the stream mouths, the sediments were found to be not particularly well suited for construction of dikes and other engineered construction. However, they were found to be well suited for agricultural uses if adequately drained. These samples were not subjected to mineral analysis due to the findings of the MSU mineral analysis which are discussed later.

A report entitled Ennis Lake Bottom Samples - Sampling and Analysis for Select Engineering Properties and Agricultural Reclamation by Morrison-Maierle, Inc., dated July 1982 is contained in Part II.

The Earth Sciences Department at MSU collected some 19 samples for mineral analysis from the bottom of Meadow Creek and from the lake bottom exposed at the mouth of the creek. There are several active gold mining operations in the Meadow Creek drainage and it was felt that this was the most optimal location to find significant amounts of gold in the sediments. The heavy metals concentrates from these samples were sent to the Montana Bureau of Mines and Geology in Butte for analysis. One half of the samples were found to have no gold content. The best sample had a content of .37-.40 ounces per ton. It was concluded by MSU that the gold content of the sediments in the most optimal location was relatively low and that the content would have to be of the order of 2-3 ounces per ton in order to be considered economically viable.

The preliminary construction costs developed by Morrison-Maierle and the preliminary economic impacts developed by T.A.P. are shown in the following table.

Summary of Engineering and Economic Phase 1 Evaluation for Alternatives A through F.

Alternative A - Higher Dam and Larger Reservoir

Alternative B - Channelization Dikes Through Reservoir

Alternative C - Channelization Dike Around Edge of Reservoir

Alternative D - Deepen Existing Reservoir

Alternative E - Eliminate Dam and Reservoir

Alternative F - Reduce Level and Size of Reservoir

Alternative	Construction Cost	Annual Economic Effect
A	$ 28,830,500	+ $ 6,822,107
B	11,429,600	+ 1,778,859
C	8,023,200	+ 2,554,734
D	283,370,340	+ 2,924,238
E	198,900	- 2,113,294
F	16,728,000*	- 1,923,184

*includes approximately $16,300,000 for replacement of the existing wood stave pipeline which may or may not be necessary

Phase 2 Review

Phase 2 was initiated by the Advisory Committee in July 1982. Although the results of the bottom sampling of Ennis Lake created a real surprise in terms of the amount of sediments, the committee felt that the study was well done and provided the answers that were sought. The gold analysis work done by MSU demonstrated that the amount of gold in the sediments was not of consequence in evaluating Alternative D, the deepening of Ennis Lake. The committee was also satisfied with the construction cost estimates prepared by Morrison-Maierle.

A major topic of discussion by the committee was the preliminary economic impacts developed by T.A.P. Specifically, the direct and indirect valuation of a day's fishing were debated. T.A.P.'s analysis utilized a figure of $72.87 as the direct value of a day's fishing and a figure of $144.21 as the indirect value of a day's fishing for non-residents. The latter figure represents the total economic benefit to those who provide services to the fisherman and the spin-off to related businesses. Some of the committee members felt these values were realistic and others felt that they were much too high. Figures used by various federal agencies were cited and they ranged as low as $7.00 per day for some agencies. The committee finally concluded that the values should be further researched in Phase 3 and that with appropriate discounts they would be satisfactory for the Phase 2 review.

After numerous discussions and meetings the Advisory Committee made the following recommendations:

Alternative A - Raise the level of the reservoir 40 feet. The committee recommended that this alternative be eliminated from further consideration for two reasons. First, Montana Power Company expressed their feelings that there were other more cost effective ways for them to increase their power generation capabilities and they would not be interested in participating in such a project. Second, the MSU Biology Department presented their views on the limnology of the "new lake." They expressed doubts that the new lake would stratify; that it would probably provide a disappointing fishery due to the high nutrient levels in the Madison River which would stimulate plant growth in the lake and would ultimately result in oxygen depleted water in the lower levels of the lake; that the colder oxygen depleted water would

cause problems in the lower river when released; and that the overenriched lake would be highly conducive to the production of blue-green algae.

Alternative B - Reduce the active reservoir surface area by 80% by diking. The committee recommended that this alternative be deleted as it accomplished the same result as Alternative C but had a higher construction cost and the annual economic impacts were less.

Alternative C - Channel the river around the reservoir. The committee recommended that this alternative be retained for further detailed study.

Alternative D - Deepen the reservoir by dredging or excavation. The committee recommended that this alternative be deleted due to the enormous quantities of materials which would have to be removed, its tremendous cost, and the determination that the gold content of the bottom materials was not sufficient to offset the construction cost.

Alternative E - Remove the dam. The committee recommended that this alternative be deleted because its preliminary annual economic impact was negative, that the Federal Energy Regulatory Commission would oppose the abandonment of the facility, and Montana Power would not support the removal of the facility.

Alternative F - Lower the reservoir level. The committee recommended that this alternative be deleted because its preliminary annual economic impact was negative and Montana Power would not support this action.

The essence of the committee's recommendation was that only Alternative C, channel the river around the reservoir, be considered in the Phase 3 detailed investigations. The Executive Committee considered the committee recommendation in August 1982. It was their feeling that in order to be responsive to considerations expressed by the Legislature at such time as the grant was approved that alternatives which involve alteration of the operation of the power generation facilities must be evaluated. Therefore, the Executive Committee directed that Alternative C - Dike around the east shore of the lake, Alternative E - Removal of the dam, and Alternative F - Lowering of the lake level, would be the alternatives considered in Phase 3.

Phase 3 Detailed Studies

Detailed work programs were developed for each of the consultants and the Phase 3 studies began in September 1982. Monthly progress meetings were held by the Advisory Committee in order to stay current with the studies. Phase 3 reports were completed by January 1983.

Engineering -

Morrison-Maierle did a very thorough job in developing preliminary engineering designs for the three alternatives. Their report considered all factors involved in the construction and operation of the facilities, presented preliminary engineering drawings, developed detailed construction cost estimates, and estimated operation and maintenance costs where applicable. The costs are summarized in the following:

Alternative	Construction Cost	O & M
C - Channel	$ 9,292,400	$30,000/yr.
E - Remove Dam	$ 1,122,800	N/A
F - Lower Lake	$ 998,300	N/A

Economic -

The economic analysis conducted by T.A.P., Inc., and their associate AMEC, Inc., also of Bozeman, thoroughly evaluated all considerations involved in the implementation of the three alternatives. Items that were considered were recreation impacts, impacts on lakefront properties, impacts on electric power generation, indirect economic impacts, construction costs, and operation and maintenance costs. A more thorough analysis by the economic consultants resulted in new values for the direct and indirect valuation of a day's fishing. These values were $7.42 and $212.17 respectively. The following Table summarizes the annualized economic effects. Construction costs were amortized at 7 7/8 percent interest over 100 years.

Alternative	Added Costs	Added Benefits	Benefit Cost Ratio
C - Channel	$ 1,015,704	$ 1,022,306	1.01
E - Remove Dam	$ 2,250,185	$ 1,584,088	0.70
F - Lower Lake	$ 656,470	$ 855,165	1.30

It should be pointed out that the increased values for fishing in the lower river were based on the assumption that the fishability of the lower river would be improved to that existing in the upper river.

might result in a lowering of the mean temperature at the powerhouse of around 1°F. The channeling of the river around the lake, Alternative C, would drop the mean temperatures at the powerhouse something less than 4°F, which would erode to around a 3°F drop at Norris Bridge and maybe 1°F at Three Forks. The report also discussed the impact the alternatives would have on maximum and minimum temperatures. It concluded that there would be some minor effects which would vary with position downstream, but that in general they would be beneficial.

Another of the requirements of the MSU environmental work program was to evaluate the anticipated biological consequences of the alternatives on the trout fishery in the lower Madison River and on the limnology of Ennis Lake. MSU directed their efforts entirely on the bypass channel, Alternative C, due to the results of their modeling which showed that lowering of the lake, Alternative F, would not have significant effects on downstream temperatures and the realization that removal of the dam, Alternative E, in theory would have the same downstream effects as the bypass channel.

MSU concluded that the primary benefits on the trout fishery in the lower river would be improved catchability, an increased margin of safety from thermal fish kills, and that these improvements would be most noticeable in the 10-15 miles immediately downstream of the powerhouse. They felt that the temperature benefits were too small to have much effect on growth rates and on numbers of larger trout. A number of other considerations which also contribute to growth rates were discussed. Present biomass of trout in the lower river is so high that it is unlikely to expect an increase with reduced temperatures.

With regard to the limnology of Ennis Lake, MSU concluded that the bypass channel would probably not have a significant effect on either the aquatic plant life or the fishery in the lake. Although the bypass would increase the flow-through time of water in the lake, the nutrient inflow would likewise be reduced. Analysis of the water quality data and a review of the analysis of the bottom samples shows that the bottom sediments are very rich in nutrients irregardless of nutrient inflow. Management of the bypassed lake with adjustable gates could provide nutrient flushing at certain times of the year which could improve the present situation.

Phase 4 Reviews

The major item of review in Phase 4 was the MSU thermal modeling report. The results of this work differed dramatically from the earlier BuRec work and suggested that Ennis Lake was causing only a minor amount of warming of the lower river, and that this warming was only affecting a 10-15 mile reach immediately below the powerhouse. Alternative F, lower the reservoir level, was predicted to make insignificant temperature changes in the lower river. Alternatives C, bypass channel, and E, remove the dam, were deemed to have similar results which would amount to an approximate 4°F reduction in daily mean temperature at the powerhouse and an approximate 3°F reduction in daily mean temperature at Norris Bridge.

During the first three months of 1983 numerous discussions and meetings took place between all involved parties, namely, Blue Ribbons, MSU, BuRec, FW&P, and the full Advisory Committee on several occasions. Some areas of agreement were found but numerous areas of disagreement still existed. MSU

The economic consultants also conducted a survey of key informants in the Ennis area to assess attitudes toward the current use and the proposed alternatives. While the survey is of use in assessing attitudes it would be improper to extrapolate the results over the entire population as interviewees were not randomly selected. The survey indicated a rather high level of use of Ennis Lake by local residents. Of the alternatives presented the east shore channel was the most acceptable.

Environmental

One of the requirements of the environmental work program was to overview the previous BuRec computer modeling work with the idea of refining certain of the predictions. MSU reviewed all of the data base and analyzed relationships between various parameters such as streamflows at various locations, streamflows versus water temperatures, air and water temperatures, and long term trends. They confined their analysis to 1977 as the greatest data base existed for this year and looked specifically at the warmest period of the year, July 15 to August 15. Some field work was done to obtain transit times through the Bear Trap Canyon below the dam. A computer modeling strategy was developed and rate coefficients for heat transfer were computed for both the river and the lake. An equilibrium temperature was likewise determined for the river.

The MSU thermal modeling work seriously questioned the earlier BuRec modeling of both the calculated values for the equilibrium termperature and the predicted temperatures to be realized in the lower river by the various alternatives. Their report concluded that lowering of the lake level, Alternative F,

qualified their results to apply solely to the year 1977, which they maintained was the only year for which sufficient data existed. Unfortunately, 1977 was a somewhat unusual year from the standpoint of flow and temperature.

Attempts were made by MSU and FW&P to extrapolate MSU's 1977 results to a "normal" year. MSU eventually concluded that such an extrapolation could not be done and little agreement was reached with regard to the FW&P projections. Through this review process the BuRec continued to support their earlier modeling results and to some extent the FW&P projections of MSU's 1977 results to a "normal" year. The USGS member of the Advisory Committee sent all pertinent reports to his agency's temperature expert who responded by both supporting and finding fault with both modeling efforts and suggesting that the BuRec and MSU get together in a new modeling effort.

MSU maintained that little additional modeling work could be done without the collection of additional data to fill in certain voids. They agreed to reanalyze their work in light of the extensive review that had occurred and to prepare their final Phase 5 report.

The Advisory Committee also reviewed the balance of the MSU environmental work, the Morrison-Maierle engineering studies, and the T.A.P.- AMEC economic analysis. A number of the committee members could not support the new value for a fishing day used in the economic study of $7.42 and expressed their thoughts that it was much too low. The economic consultant explained that their research had identified a range of values and that they were the most comfortable with the $7.42 value in that it evolved from an EPA model for this region. They conceded that fishing the Madison River might

be more highly valued by some fisherman and agreed to present an alternate set of computations based on a somewhat higher value. The engineering and economic work was predicated on the results of the BuRec modeling and the conclusions were in some ways not pertinent to the MSU modeling results. However, the decision was made to finalize these reports based on the BuRec work as the modeling issue was still unresolved, the time remaining in the grant was limited, and the grant funds were substantially expended for these areas of work. Review comments were provided to all three consultants for incorporation in their Phase 5 final reports.

Phase 5 Final Reports

The final reports were received from all the consultants by June 1983. Copies of each of these reports are contained in Part II and are identified below:

Engineering	-	Preliminary Engineering Design Report Madison River Thermal Program By Morrison-Maierle, Inc. June 1983
Economic	-	An Economic Evaluation of Proposed Solutions to the Thermal Pollution Problem on the Lower Madison River by TAP, Inc. and AMEC, Inc. June 1983
Environmental	-	Thermal Modeling for the Madison River - Ennis Reservoir System; Effects of Modification on Downstream Temperatures By Daniel Goodman, Montana State University March 1983
		Potential Biological Effects of Proposed Modifications to Ennis Reservoir and Ennis Dam By Dept. of Biology, Montana State University April 1983

Engineering -

Morrison-Maierle's final report was substantially the same as their Phase 3 report with only minor changes noted. The cost estimates for the three alternatives were unchanged and are summarized in the following:

Alternative	Construction Cost	O & M
C - Channel	$ 9, 292,400	$30,000/yr.
E - Remove Dam	1,122,800	N/A
F - Lower Lake	998,300	N/A

Economic -

The economic final report prepared by T.A.P., Inc., and AMEC, Inc., reflected a number of changes in accordance with the input received from the Advisory Committee during the Phase 4 reviews. It included an alternate set of calculations based on a $19.00 value for a day's fishing. However, the consultants indicated their preference of using the original value of $7.42. The report presented the results of the economic analysis by computing the net present value for the present "baseline" situation and for each of the alternatives for an assumed project life of fifty years. This information is summarized in Figure 3. The best alternative is F, lower the lake, followed closely by C, bypass channel, with Alternative E, remove dam, being the least favorable.

The economic consultants pointed out that a host of assumptions were employed in their analysis and that there are some important limitations in its use. Some of these limitations are as follows:

1. The uncertainty surrounding the anticipated improvement in fishing in the lower river. This is extremely important as demonstrated in Figure 3. Under the assumptions used, the recreation values went from a figure slightly less than the value of electricity in the baseline to double the value of the electricity for the two best alternatives.

2. The change in land use. Lands created by lowering or eliminating the lake were valued as agriculture whereas they might very well be used for other higher value uses.

3. The valuation of the hydroelectric generating facility. The analysis considered the cost of replacing the power generated by the Ennis Lake facility but did not consider the additional operation, maintenance, replacement and possible renovation costs required of the Ennis Lake facility and supply and demand conditions over the next fifty years.

Figure 3

Comparison of Net Present Value of Each of the Proposed Alternatives with the Baseline. /4

Item	Baseline	Channel	Diff /3	Lower Lake	Diff	Remove Dam	Diff
		(x 1,000,000)					
Recreation /1	$71.5	144.3	72.8	138.3	66.8	137.7	66.2
Real Estate	0	0	0	4.6	4.6	17.4	17.4
Electricity	81.6	76.7	(-4.9)	70.6	(-11.0)	3.1	(-78.5)
Subtotal	153.1	221.0	67.9	213.5	60.4	158.2	5.1
Construction Costs /2	0	11.2	(-11.2)	1.2	(-1.2)	1.3	(-1.3)
Total	153.1	209.8	56.7	212.4	59.3	156.9	3.8

/1 Ennis Lake and Lower Madison River.

/2 No interest is charged on the construction costs.

/3 This is the difference between the channel alternative and the baseline. A similar figure is calculated for the lower lake and remove dam alternative.

/4 From TAP, Inc., and AMEC, Inc., economic evaluation, 1983.

Environmental -

The final report by MSU on the thermal modeling was a refinement of the Phase 3 report and involved some further analysis to attempt to answer some of the questions raised during the lengthy Phase 4 review of this work. The major summary points of the study are as follows:

1. An analysis of the 11 years of temperature records suggests that 83°F would be the daily maximum water temperature as the 100 year event.

2. There is no evidence of progressive worsening of the thermal regime in the reservoir-river system.

3. The major role of the reservoir in the thermal dynamics of the river is the delay it imposes on the water and the warming of the water to the approximate equilibrium temperature of the lower river.

4. If the reservoir were bypassed or drained the model for the 1977 year suggests that the result would be a reduction of daily mean temperatures of approximately 4°F at the dam site, decaying to less than 2°F at Norris Bridge and 1°F at Three Forks.

5. The reservoir surpresses the daily temperature cycle and if it were bypassed or drained a normal daily cycle would be established. The model suggests that the dominant thermal effect would be a reduction of the daily minimum temperature in a stretch immediately

downstream of the reservoir and a reduction in the daily maximum temperature in a stretch centered around half a day's flow downstream of the reservoir.

6. The data used in the modeling was not entirely satisfactory and a summer of systematic temperature measurement at key locations is recommended before further elaboration of predictions.

7. The value of the rate coefficient was the least secure element of the modeling and further efforts would be best directed at additional study to support estimation of this parameter.

The MSU final report on the fishery in the lower river and on the limnology of Ennis Lake was essentially the same as the Phase 3 report. For continuity its results are summarized as follows:

1. The bypassing or draining of the reservoir are the only alternatives which would have any significant effect on the downstream water temperatures.

2. The primary benefits on the trout fishery in the lower river would be -
   a) improved catchability
   b) increased margin of safety from thermal fish kills
   c) improvements would be most noticeable in the 10-15 miles immediately downstream of the reservoir.

3. Present biomass of trout in the lower river is so high that it is unlikely to expect an increase with reduced temperatures.

4. The bypass channel would probably not have a significant effect on either the aquatic plant life or the fishery in the reservoir.

5. Management of the bypassed lake with adjustable gates could provide nutrient flushing at certain times of the year which could improve the present situation.

BUREAU OF RECLAMATION ADDITIONAL MODELING WORK

A significant difference of opinion continued to exist between the two modeling groups, MSU and BuRec, as regards the temperature levels which could be achieved in the lower river through implementation of the various alternatives. The entire results of the Thermal Study were really dependent on resolution of this question. The Advisory Committee therefore determined that a third opinion would have to be obtained from another qualified expert.

Dr. Robert George of the BuRec headquarters office in Denver, Colorado, had become involved to some extent in the Phase 4 reviews of the modeling. Dr. George was considered to be the BuRec temperature modeling expert and had access to the BuRec newest temperature modeling programs. Because of his knowledge of the previous modeling studies and the data available, he was felt by the committee to be the logical person to provide an additional opinion. Some $5,000 in grant funds were rebudgeted to contract with BuRec for Dr. George's assistance.

The final results of Dr. George's work was transmitted to the Advisory Committee on June 10, 1983, in a report entitled Applications of Qual II to Lower Madison River. This report is contained in Part II. One of Dr. George's major findings was a significant error in the meteorological data furnished to BuRec and utilized in their original modeling effort. In his opinion this was a major factor in the differences in the results of the BuRec and MSU models. His specific conclusions were:

1. The temperature increases about 1°F between Ennis Bridge and Ennis Lake.
2. The lake causes an increase of 3°F from the head of the lake to the powerhouse.
3. Routing the water through the lake in channels similar to the channel above the lake would reduce the 3°F rise by about 1°F.

In essence, Dr. George concluded that bypassing or draining the lake would result in a 1°F reduction in daily mean temperatures at the powerhouse which is less than the 4°F reduction determined by MSU. He pointed out the limitations in the data used in the modeling studies, how this resulted in a constraint to the modeling efforts, and set forth data requirements in order to correctly model the river.

GRANT EXTENSION

A problem which had constrained all of the modeling work was the fact that the water temperature data had not been collected with modeling as an objective. Several monitoring stations were not located in the most optimal location

and there were no stations from Varney Bridge to Ennis Lake, a distance of approximately 14 miles. In 1977 the Fraley Study collected temperature data at Ennis Bridge, about five miles above Ennis Lake, which was the reason that MSU chose to model this particular year. All parties agreed that it would be very helpful to fill in the data gaps and reanalyze the models.

Discussions took place with the Department of Natural Resources and Conservation (DNRC) on the possibilities of extension of the grant to allow data collection for the July 15 - August 15 period during the summer of 1983. FW&P had agreed to perform the additional monitoring work. As this work would not involve any increase in grant funding and as it would help to resolve remaining questions about the adequacy of the modeling, DNRC agreed to extend the grant period from June 30, 1983, to December 31, 1983. The grant extension was accomplished by means of a grant amendment dated May 26, 1983.

SUMMER 1983 DATA

FW&P installed thermographs in the upper Madison River at McAtee Bridge, 25 miles above Ennis Lake, Varney Bridge, 14 miles above the lake, Ennis Bridge, 5 miles ahove the lake, and at a station identified as channels which was located ¼ mile above the lake. Below Ennis Lake a USGS thermograph was located at the powerhouse and a FW&P thermograph was located at Norris Bridge, 11 miles below the powerhouse. Daily flow data and daily meteorological data were also gathered.

All of this data for the period July 15 - August 15, 1983, was transmitted to MSU and to both the Billings Regional Office and the Denver Headquarters Office of the BuRec by mid-September.

FINAL MODELING ANALYSIS

A meeting was held in early October, 1983, which included the modelers, MSU and BuRec, and BR, FW&P and DNRC. Purpose of the meeting was to discuss the new data and review its implications on the individual modeling efforts. This was an extremely productive meeting and resulted in a concensus on the modeling results. MSU comments were contained in a letter dated November 12, 1983, and BuRec comments in a letter dated December 1, 1983. Both of these letters are contained in Part II.

The MSU comments are summarized in the following:

1. The summer of 1983 was again an atypical year. Ennis Lake did not reach its seasonal maximum temperature during the monitoring period. Due to the extraordinary warm weather the water leaving the lake was below the equilibrium temperature of the lower river. The thermal behavior in the Bear Trap Canyon was unusual. The data at the powerhouse and at Norris Bridge was not sufficient to calculate a sensible equilibrium temperature.

2. The transit time data for the upper river and the lower river below the Bear Trap Canyon were acknowledged as being faster than that used by MSU in their analysis. However, transit times in the Bear

Trap were consistent with MSU. The warming rate implied for the upper river from the 1983 data was consistent with the rate used by MSU in their analysis.

3. The thermal behavior of the Bear Trap Canyon was quite different than other stretches of the river during 1983. Under some conditions the Bear Trap would not cool off at night like other stretches.

4. The new data confirmed similar results to MSU's previous analysis. A bypass channel with thermal dynamics similar to the upper river would result in a 4°F drop in mean temperatures at the powerhouse, a 2°F drop at Norris Bridge, and less than a 1°F drop at Three Forks. Dr. George's (BuRec) results predicted temperature drops of about one-half of these values.

5. If the Bear Trap Canyon does have worse thermal dynamics at certain times, then there may be some benefits of increasing flow rates to move water through the Bear Trap as rapidly as possible. This may make several degrees difference during the worst warm periods.

6. It would be worthwhile to gather additional temperature data on the Bear Trap to confirm or refute the hypothesis that it would be advantageous to speed water through that section during the warmest periods.

Comments from Dr. Robert George of the BuRec are summarized in the following:

1. The temperature rise from Ennis Bridge to Ennis Lake is about 1°F.

2. Temperature increase in the lake varies from year to year and is a function of the hydrological and meteorological conditions during the year. A range of temperature rise is 3 to 5°F.

3. Channelizing the flow around the reservoir will only reduce this temperature rise by about 1 to 1.5°F, at most. By completely maintaining the flow as a river a 3°F decrease might be achieved.

4. Temperatures at the dam are about 2°F lower than the computed and observed temperatures at Norris Bridge.

5. The natural diurnal variation of the stream is about ±4 to ±5°F. This variation is dampened out by the lake and also would be dampened out by the proposed dike to a value of about ±1°F at the dam. The diurnal fluctuation would return to about ±4°F at Norris Bridge.

Dr. George concludes with an observation that the most practical solution would be to operate the lake at reduced levels during the hot period and measure the resulting temperatures. This would answer most of the questions and would also be the least costly alternative to manage the system.

CONCLUSIONS AND RECOMMENDATIONS

The conclusions derived from the Madison River Thermal Study by the Director of the Blue Ribbon APO are as follows:

1. The original BuRec modeling work developed temperature projections for the lower Madison River for years 1973 and 1977 after various alterations were assumed made to Ennis Lake and/or Dam. These projections suggested that dramatic reductions in temperature levels could be achieved, particularly in 1973. The current study found these conclusions to be erroneous, primarily due to a significant error in the meteorological data furnished to BuRec. This is significant as the original BuRec modeling work was the basis for the Renewable Resources Development Fund grant and for the work attempted by this study.

2. The modeling work performed under this study suggested that the draining of Ennis Lake or the bypassing of the lake with a channel, which would maintain the thermal dynamics of the upper river, would result in the lowering of daily mean temperatures in the lower river as follows:

Ennis Dam Powerhouse	2 to 4°F
Norris Bridge	1 to 2°F
Three Forks	less than 1°F

The draining or bypassing of Ennis Lake would also establish a normal daily temperature cycle in the 10-15 miles of river immediately below the lake. This would effect a reduction of the daily minimum temperatures in a stretch immediately downstream of the dam and a reduction in daily maximum temperatures in a stretch centered around half a day's flow downstream. The reduction in the daily maximum, at the point where the effect would be strongest, would, on the basis of the available data, be more than 4°F, decaying essentially to zero both upstream toward the dam, and downstream toward Three Forks. The reduction in the daily minimum, at the dam, where the effect would be strongest, would, on the basis of the available data, be by more than 7°F, but would decay rapidly with distance from the dam site.

3. The principal effects on the trout fishery of the lower Madison River by draining or bypassing Ennis Lake would be to improve catchability and to provide an increased margin of safety from thermal fish kills. These improvements would primarily occur in the 10-15 miles immediately downstream of Ennis Lake.

4. Bypassing Ennis Lake would probably not have a significant effect on either the aquatic plant life or the fishery in the lake and management of the bypassed lake with adjustable gates could provide nutrient flushing at certain critical times of the year.

5. The estimated construction costs of the alternatives which result in temperature improvement in the lower river are as follows:

Bypass channel	$9,292,400
Drain the lake	$1,122,800

6. The economic analysis calculated the net present value of the present baseline and the bypass and drain the lake alternatives as follows:

	Baseline	Bypass Channel	Drain the Lake
Recreation	$71,500,000	$144,300,000	$137,700,000
Real Estate	-0-	-0-	17,400,000
Electricity	81,600,000	76,700,000	3,100,000
Subtotal	153,100,000	221,000,000	158,200,000
Construction Costs	-0-	(-)11,200,000	(-)1,300,000
Total	$153,100,000	$209,800,000	$156,900,000

These net present values were based on the assumption that the lower river would be improved to where fishing would be comparable to the upper river and that non-resident fishermen would increase so as to be equal in number to resident fishermen. The modeling results have shown that only 10-15 miles (30-40%) of the lower river would be improved and that such improvement would probably be to some lesser level of catchability than the upper river.

Therefore, an attempt has been made to recalculate the recreation benefits based on a lesser increase in fishing in the lower river.

This calculation has been made for the bypass channel only, as any real loss in recreation value for the drain the lake alternative results in a lesser net present value than the current or baseline situation. This analysis takes the present users of the lower river, 22,320 residents and 5,431 non-residents per year (80:20), and assumes that the resident fishermen remain the same and the non-residents double to a value of 11,000. The ratio of residents to non-residents then becomes 70:30. The results of this analysis are shown in the following:

	Baseline	Bypass Channel
Recreation	$ 71,500,000	$ 88,700,000
Real Estate	-0-	-0-
Electricity	81,600,000	76,700,000
Subtotal	153,100,000	165,400,000
Construction Costs	-0-	(-)11,200,000
Total	$153,100,000	$154,200,000

For all intensive purposes, the net present values are the same. The increase in recreation value is offset by the loss of electrical power and the construction costs.

Based on the assumptions and limitations of this economic analysis, it would appear that the net present value of the most favorable alternative would not result in a significant change in the economic value of Ennis Lake and the lower Madison River.

Recommendations by the Director of Blue Ribbons APO for future actions are as follows:

1. Although the Thermal Study has shown that Ennis Lake does cause some increase in temperatures in the lower river and does have an effect on the catchability of the fish, the MSU temperature modeling suggests that the maximum 100-year temperature event will be just below a lethal level. The economic analysis does not suggest a significant increase in economic values with implementation of temperature reduction alternatives. The results of these studies do not warrant a recommendation that a temperature reduction alternative be implemented at the present time.

2. The dam and powerhouse at Ennis Lake are over 75 years old and at some time in the future significant maintenance, replacement or renovation costs can be presumed. At that time the economic analysis should be reviewed taking these costs into consideration.

3. MSU suggested that additional temperature monitoring and modeling should be done in the Bear Trap Canyon and that increasing the flows during the warmest season through the Bear Trap may provide some improvement in the lower river. This work should be accomplished.

4. Dr. Robert George of the BuRec suggested a trial lowering of the Ennis Lake level for a week or so during the warmest season and temperature monitoring below the lake to see what the actual results

would be. If the public relations aspects of this action could be dealt with, this would be a worthwhile experiment.

REFERENCES CITED

Blue Ribbons APO, 1977
"Madison River Thermal Study", Working Paper, (June 1977)

Blue Ribbons APO, 1979
"Final Report and Water Quality Management Plan", (August 1979)

Dooley, John, and Horn, James, 1980
"Report on Lower Madison River - Ennis Lake Temperature Studies", Working Paper, Water and Power Resources Service (Bureau of Reclamation), (September 1980)

Fraley, J. J., 1978
"Effects of Elevated Summer Water Temperatures Below Ennis Reservoir on the Macroinvertebrates of the Madison River, Montana", Unpublished Montana State University Thesis, (1978)

George, Robert, 1983
"Application of Qual II to Lower Madison River", Bureau of Reclamation, Working Paper for Blue Ribbons, (June 1983)

George, Robert, 1983
Correspondence transmitting comments on final temperature modeling results to Blue Ribbons, December 1, 1983.

Montana Department of Fish, Wildlife and Parks, 1977
Job Progress Report, No. F-9-R-25

Montana Department of Fish, Wildlife and Parks, 1978
Job Progress Report, No. F-9-R-26

Montana Department of Fish, Wildlife and Parks, 1979
Job Progress Report, No. F-9-R-27

Montana Department of Fish, Wildlife and Parks, 1980
Job Progress Report, No. F-9-R-28

Montana Department of Fish, Wildlife and Parks, 1981
Job Progress Report, No. F-9-R-29

Montana Department of Health & Environmental Sciences, 1975
"Upper Missouri Headwaters Basin Plan", (1975)

Montana State University, 1982
Correspondence and discussions with Earth Science Department on gold content of bottom samples from Ennis Lake and Meadow Creek, (May-June 1982)

Montana State University, 1982
"Thermal Modeling for the Madison River - Ennis Reservoir System", Department of Biology, Working Paper for Blue Ribbons, (December 1982)

Montana State University, 1983
"Potential Biological Effects of Proposed Modifications to Ennis Reservoir and Ennis Dam", Department of Biology, Working Paper for Blue Ribbons, (January 1983)

Montana State University, 1983
"Thermal Modeling for the Madison River - Ennis Reservoir System", Department of Biology, Final Report for Blue Ribbons, (March 1983)

Montana State University, 1983
"Potential Biological Effects of Proposed Modifications to Ennis Reservoir and Ennis Dam", Department of Biology, Final Report to Blue Ribbons, (April 1983)

Montana State University, 1983
Correspondence from Dr. Daniel Goodman, Department of Biology, commenting on final temperature modeling results, November 12, 1983.

Morrison-Maierle, Inc., 1982
"Ennis Lake Bottom Samples - Sampling and Analysis for Select Engineering Properties and Agricultural Reclamation", Final Report for Blue Ribbons, (July 1982)

Morrision-Maierle, Inc., 1982
"Preliminary Engineering Design Report, Madison River Thermal Program", Working Paper for Blue Ribbons, (June 1982)

Morrison-Maierle, Inc., 1982
"Preliminary Engineering Design Report, Madison River Thermal Program", Working Paper for Blue Ribbons, (December 1982)

Morrison-Maierle, Inc., 1983
"Preliminary Engineering Design Report, Madison River Thermal Program", Final Report for Blue Ribbons, (June 1983)

TAP, Inc., 1982
"Phase One Economic Evaluation", Working Paper for Blue Ribbons, (June 1982)

TAP, Inc., 1982
"Phase One Economic Evaluation - Revisions", Working Paper for Blue Ribbons, (July 1982)

TAP, Inc. and AMEC, Inc., 1982
"An Economic Evaluation of Proposed Solutions to the Thermal Pollution Problem on the Lower Madison River", Working Paper for Blue Ribbons, (December 1982)

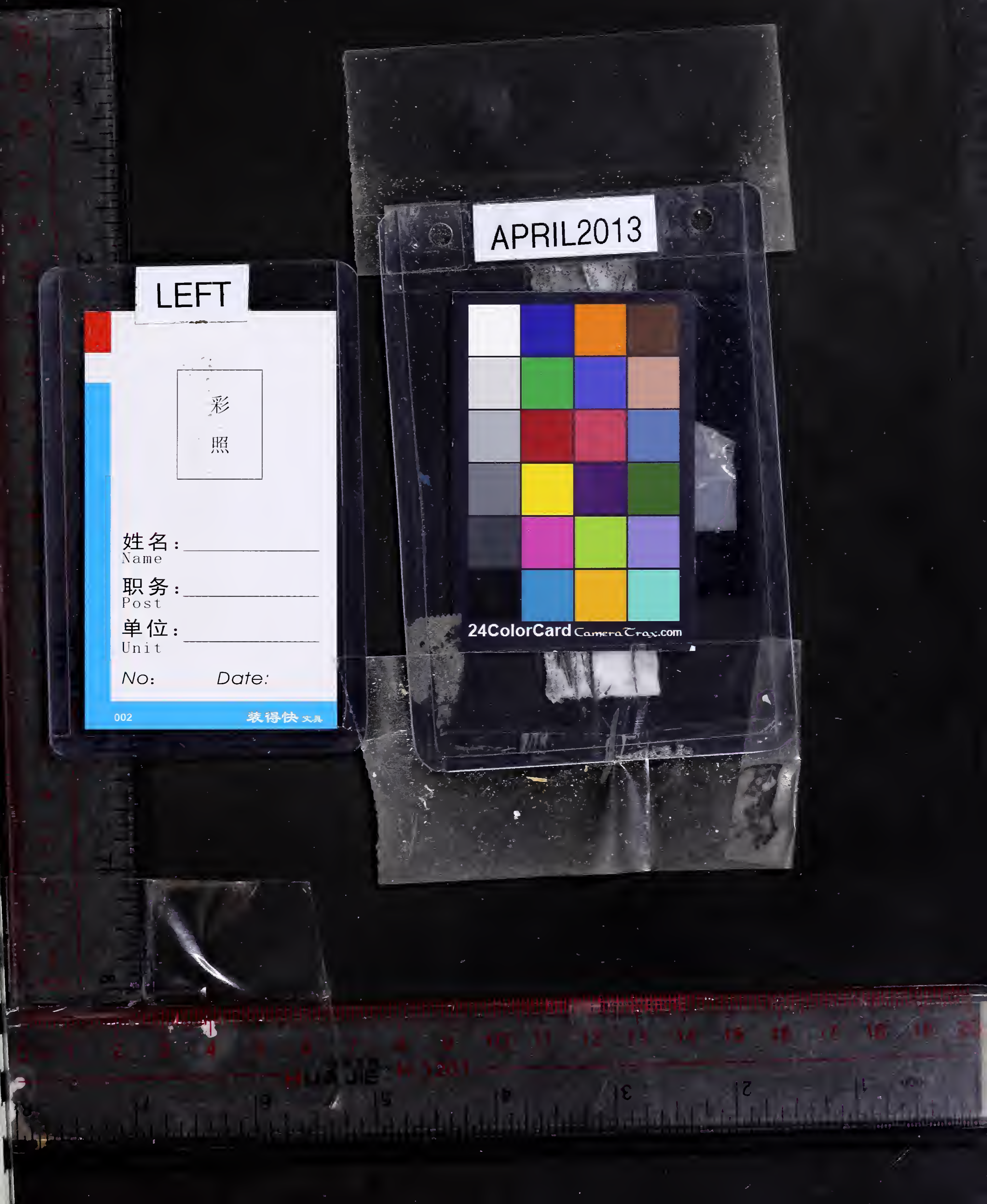
TAP, Inc. and AMEC, Inc., 1983
"An Economic Evaluation of Proposed Solutions to the Thermal Pollution Problem on the Lower Madison River", Final Report for Blue Ribbons, (June 1983)

TAP, Inc. and AMEC, Inc., 1983
"Survey of Key Informants in the Ennis Area", Final Report for Blue Ribbons, (June 1983)

TAP, Inc. and AMEC, Inc., 1983
Personal Communication and Computer Analysis of Modified Economic Analysis, (December 1983)

U. S. Geological Survey, 1977, 78, 79
Correspondence, meetings and discussions with regard to the Thermal Infrared Mapping and Analysis for the Madison River.

Vincent, Richard, Dooley, John, and Horn, James, 1981
"Madison River Thermal Simulation Study", Working Paper, Montana Department of Fish Wildlife and Parks and Water and Power Resources Service (Bureau of Reclamation), (February 1981)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